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VERIFICATION OF INTERIM SIMULATED ATMOSPHERIC TURBULENCE TAPES

Final Report
Contract NAS8-33714

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LIST OF SYMBOLS

English Symbols

Symbol	Definition
a	von Karman constant (1.339)
$h(\ell)$	discrete impulse response function
$h(t)$	impulse response function
L	characteristic length scale
t	dimensionless time ($V\tau/aL$)
T	dimensionless time step ($V\Delta\tau/aL$)
u_i	gust velocity component
V	magnitude of vehicle velocity
x_i	Cartesian coordinate component
$X(n)$	white noise input
$Y_x(n)$	simulated turbulence output based on $X(n)$

Greek Symbols

Symbol	Definition
τ	time
$\Phi_{ii}(\Omega_1)$	one-dimensional gust spectrum with dimensionless wave numbers
$\Phi_{ii/jj}(\Omega_1)$	one-dimensional gust gradient spectrum with dimensionless wave numbers
ω	frequency
Ω	dimensionless frequency ($aL\omega/V$)

1. INTRODUCTION

During horizontal and near-horizontal flight of the Space Shuttle Orbiter, the effects of atmospheric turbulence on the vehicle are crucial in establishing the Space Shuttle design, control, and human pilot effects. The effects of both turbulent gusts and gust gradients (shears) must be taken into account. By means of a non-recursive turbulence simulation model, twelve simulated turbulence time series for gusts and gust gradients were generated as part of a previous investigation [1]. The current investigation has been concerned with the spectral analysis of these time series.

Section 2 provides a description of the results of the spectral analysis of the time series based on the use of Fourier transform theory. A comparison between the computed spectra and the corresponding von Karman theoretical spectra is also included. In addition, an explanation is provided of a basic difference between the computed and theoretical spectra which has been identified as a result of the comparison. Conclusions and recommendations are presented in Section 3 while references cited are listed in Section 4.

2. SPECTRAL ANALYSIS RESULTS

As previously reported [1] a non-recursive turbulence simulation model has been incorporated into a digital computer program, TBSIM. This program, operating on the HP-21MX digital computer in the MSFC Space Sciences Laboratory, was used to generate a set of dimensionless time series representing atmospheric turbulent gusts and gust gradients. These time series, stored on magnetic tape, have been spectrally analyzed by means of Fourier transform theory.

2.1 CHARACTERISTICS OF DIMENSIONLESS TIME SERIES

The sampling interval for each time series corresponds to the *dimensionless* time step T $(=\pi/\Omega_{1N})$. The corresponding *dimensional* time step can be obtained by the relation

$$\Delta\tau = \pi a L/(V\Omega_{1N})$$

The value of the Nyquist cutoff frequency Ω_{1N} for each spectrum is provided in Table 2-1. The dimensionless time step and number of time steps for each series are also indicated in the same table. The *dimensionless* gust and gust gradients represented by the amplitude of the series can be converted to *dimensional* form by multiplying by the appropriate normalization constants.

2.2 CHARACTERISTICS OF MAGNETIC TAPES

Each of the twelve simulated turbulence time series (corresponding to the three gust spectra and the nine gust gradient spectra) is written on a separate nine-track magnetic tape as indicated in Table 2-1. Pertinent characteristics of the tapes are summarized in Table 2-2.

The first record on each tape contains a 34-character alphanumeric descriptor. The second record contains the spectrum identification (NINT), the number of points in the time series (MMAX), and the time series step size, (T). The format for this record is "2I10,5X,E14.7". Following these two records, the time series is stored on tape as MMAX records. Each such record consists of the time (ST) and the corresponding value of turbulent gust or gust gradient (Y). The format for these records is "E14.7,2X,E14.7".

TABLE 2-1. MAGNETIC TAPES FOR SIMULATED TURBULENCE TIME SERIES

Tape No.	Spectrum	Dimensionless Nyquist Cutoff Frequency, Ω_{1N}	Dimensionless Time Step	Number of Time Steps
1	Φ_{11}	300.0	.01047	30,000
2	Φ_{22}	285.0	.01102	10,000
3	Φ_{33}	285.0	.01102	10,000
4	$\Phi_{11/11}$	205.0	.01532	30,000
5	$\Phi_{11/22}$	260.0	.01208	30,000
6	$\Phi_{11/33}$	225.0	.01396	30,000
7	$\Phi_{22/11}$	193.0	.01628	30,000
8	$\Phi_{22/22}$	225.0	.01396	30,000
9	$\Phi_{22/33}$	215.0	.01461	30,000
10	$\Phi_{33/11}$	195.0	.01611	30,000
11	$\Phi_{33/22}$	245.0	.01282	30,000
12	$\Phi_{33/33}$	210.0	.01496	30,000

TABLE 2-2. MAGNETIC TAPE CHARACTERISTICS

Number of Tracks:	9
Header Type:	non-label
Character Type:	ASCII
Recording Density:	800 bits per inch

2.3 SPECTRAL ANALYSIS

In order to establish the spectral characteristics of the output of the turbulence model, a Fast Fourier transform (FFT) of the output must be obtained. Based on the results of the preceding study [1], FFT4 was selected for obtaining the spectra of the turbulence time series described in the preceding subsections.

By means of FFT4 operating on the HP-21MX computer, twelve turbulent spectra have been generated corresponding to the twelve series as stored on Tapes 1 through 12, respectively. Plots of these spectra are presented in Figures 2-1 through 2-12.

In each of the twelve figures the appropriate von Karman theoretical spectra is also plotted. A comparison of the computed and theoretical spectra reveals one basic difference: the magnitudes of spectra based on simulated turbulence are larger than the corresponding theoretical spectra. As indicated in each figure, the ratio of the computed spectra to the theoretical spectra has been found to be $1/\sqrt{T}$. This ratio is the reciprocal of the "normalization factor" which had been used to correct for the effect of digitizing [1,2]. A careful review of the earlier work by Perlmutter [3], who appears to have originated this "normalization factor", has revealed that no such factor is actually appropriate. Thus the magnitude difference can be corrected by simply multiplying the existing time series by $\sqrt{T}$.

2.4 REVISED GENERATION PROCEDURE

Based on the preceding explanation the original procedure [1] for generating turbulence time series has been revised. The simulated turbulent signal is generated according to the relation

$$Y_x(n) = T \sum_{j=-N}^{+N} h(j)\ X(n-j) \tag{1}$$

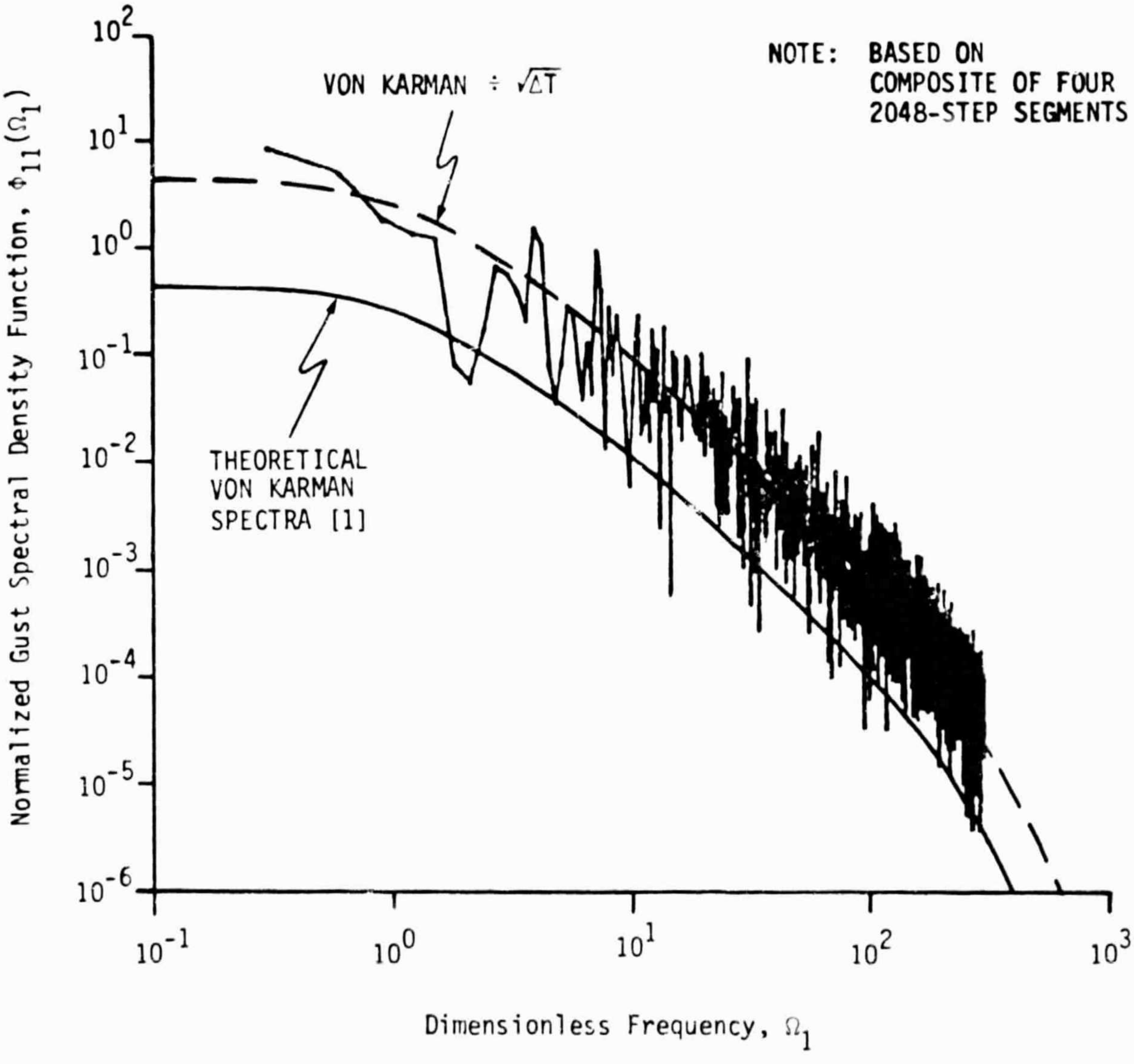

Figure 2-1. Computed Φ_{11} Spectra Based on Analysis of Tape 1.

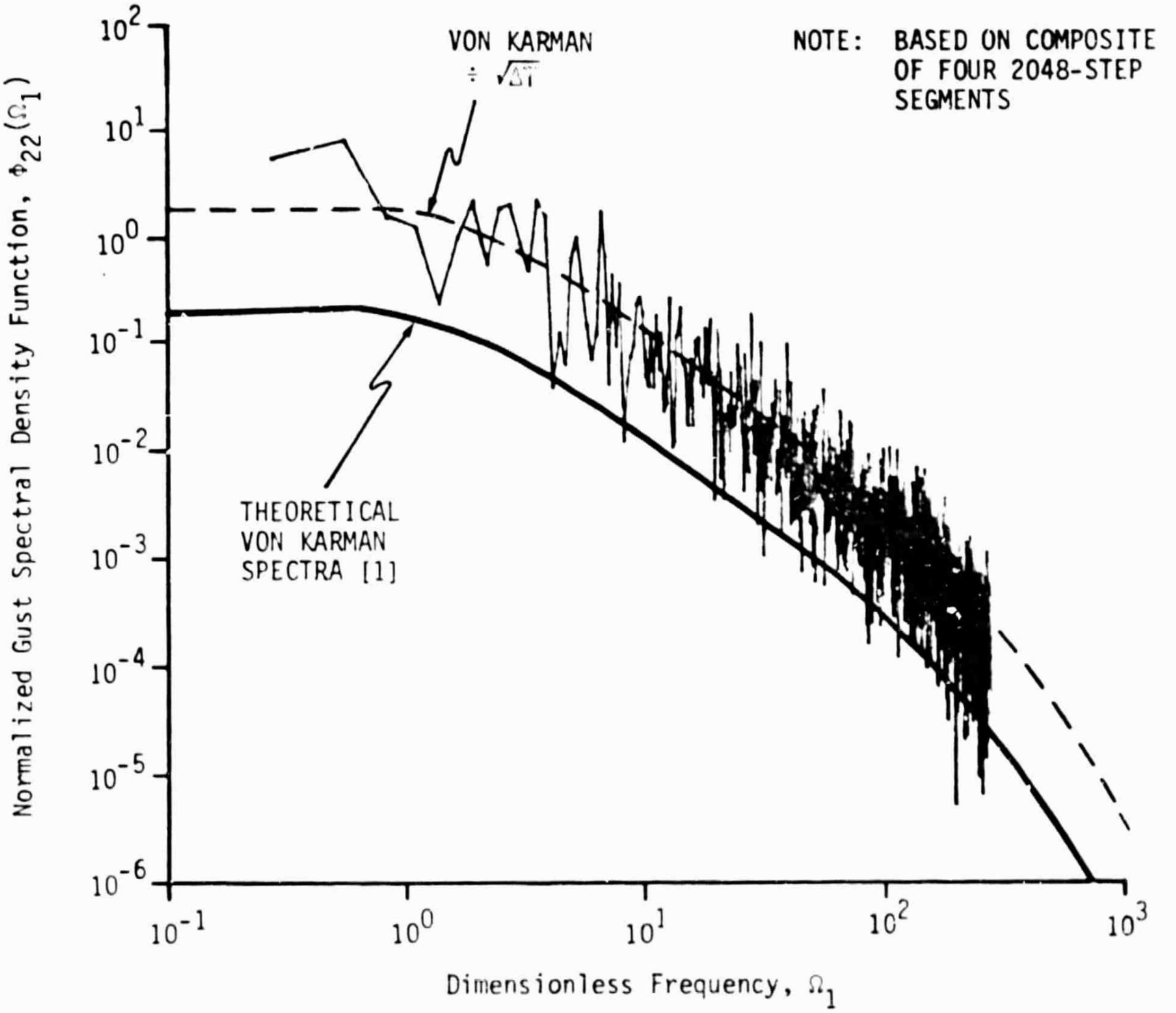

Figure 2-2. Computed Φ_{22} Spectra Based on Analysis of Tape 2

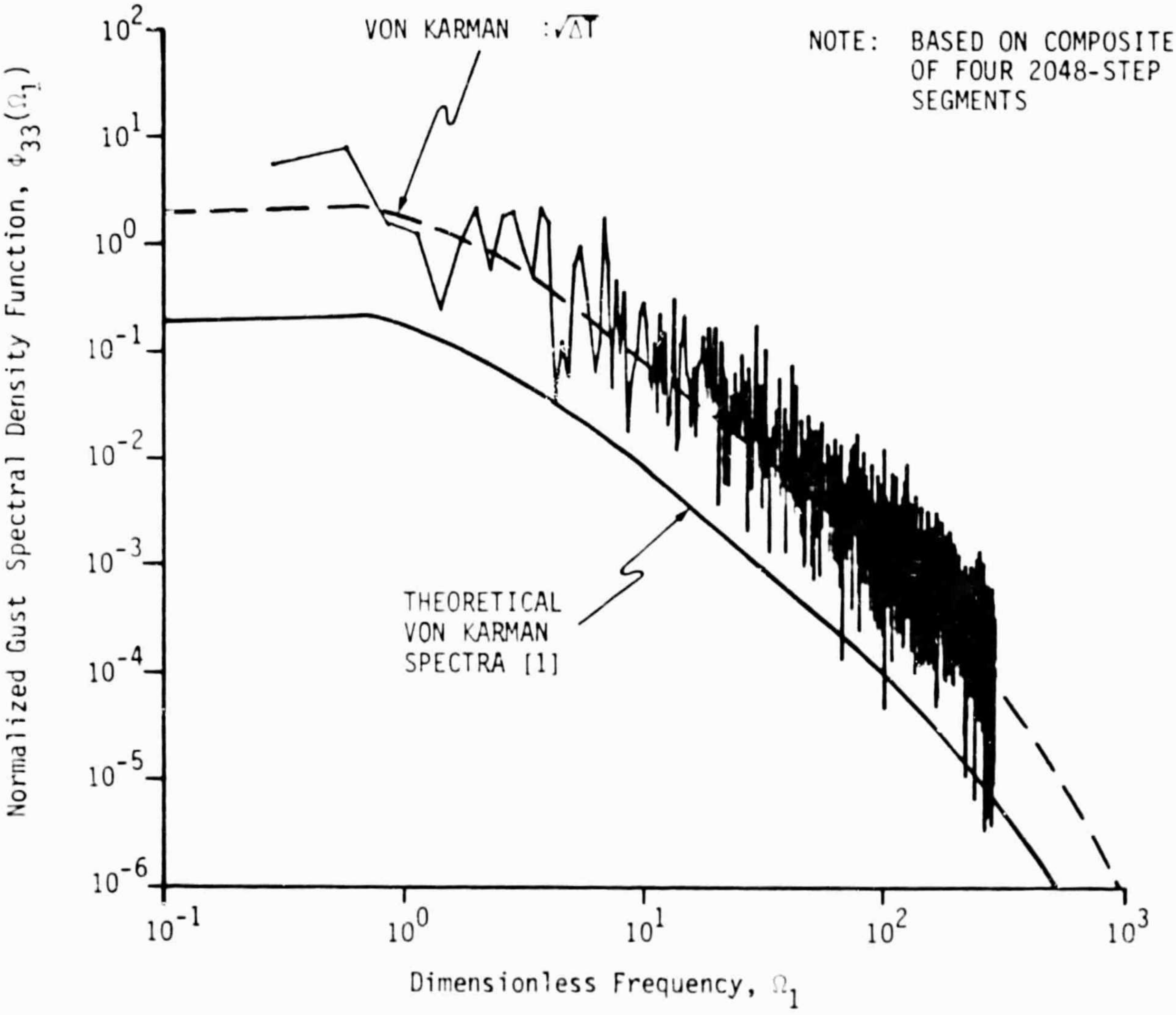

Figure 2-3. Computed Φ_{33} Spectra Based on Analysis of Tape 3.

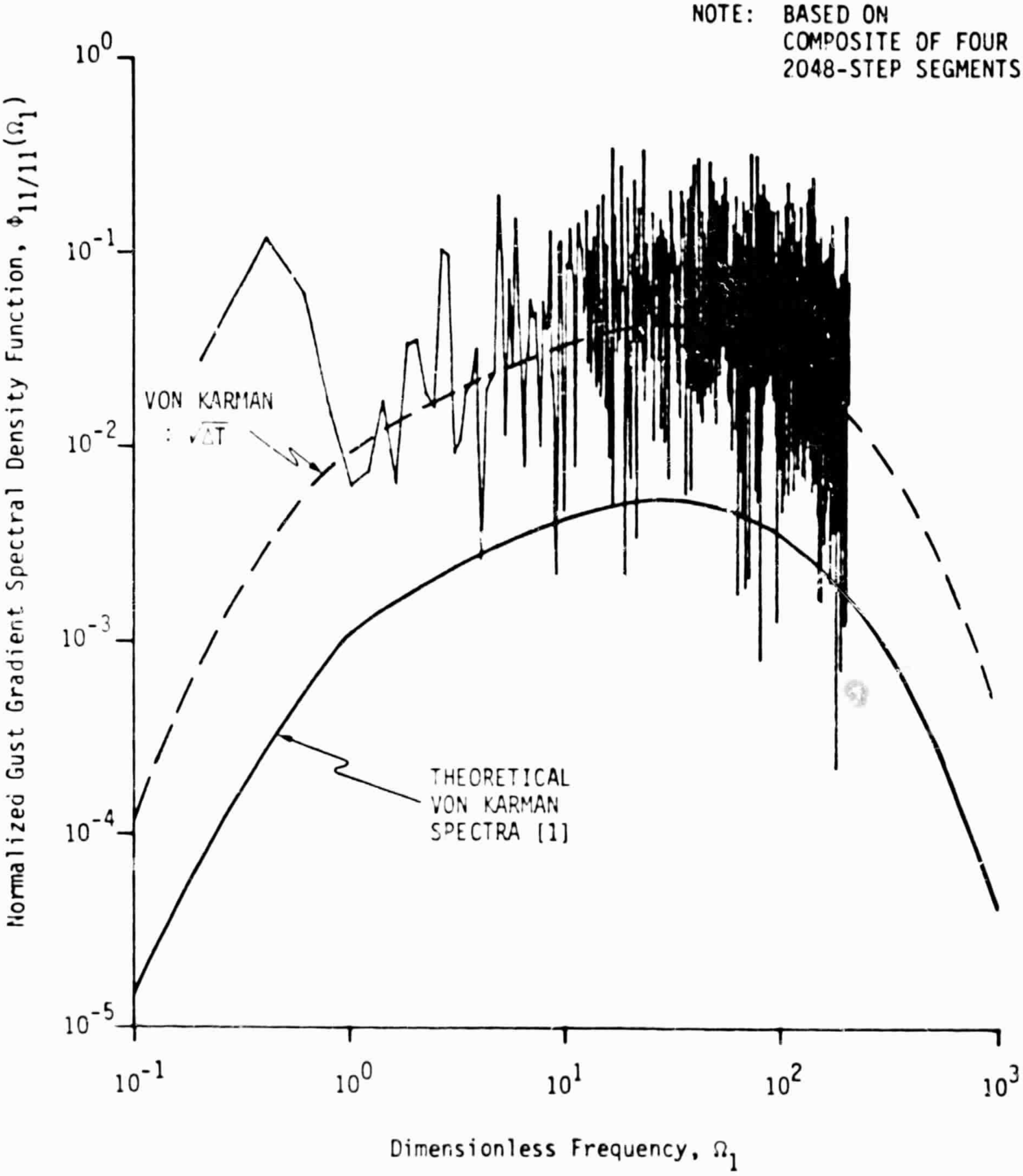

Figure 2-4. Computed $\Phi_{11/11}$ Spectra Based on Analysis of Tape 4

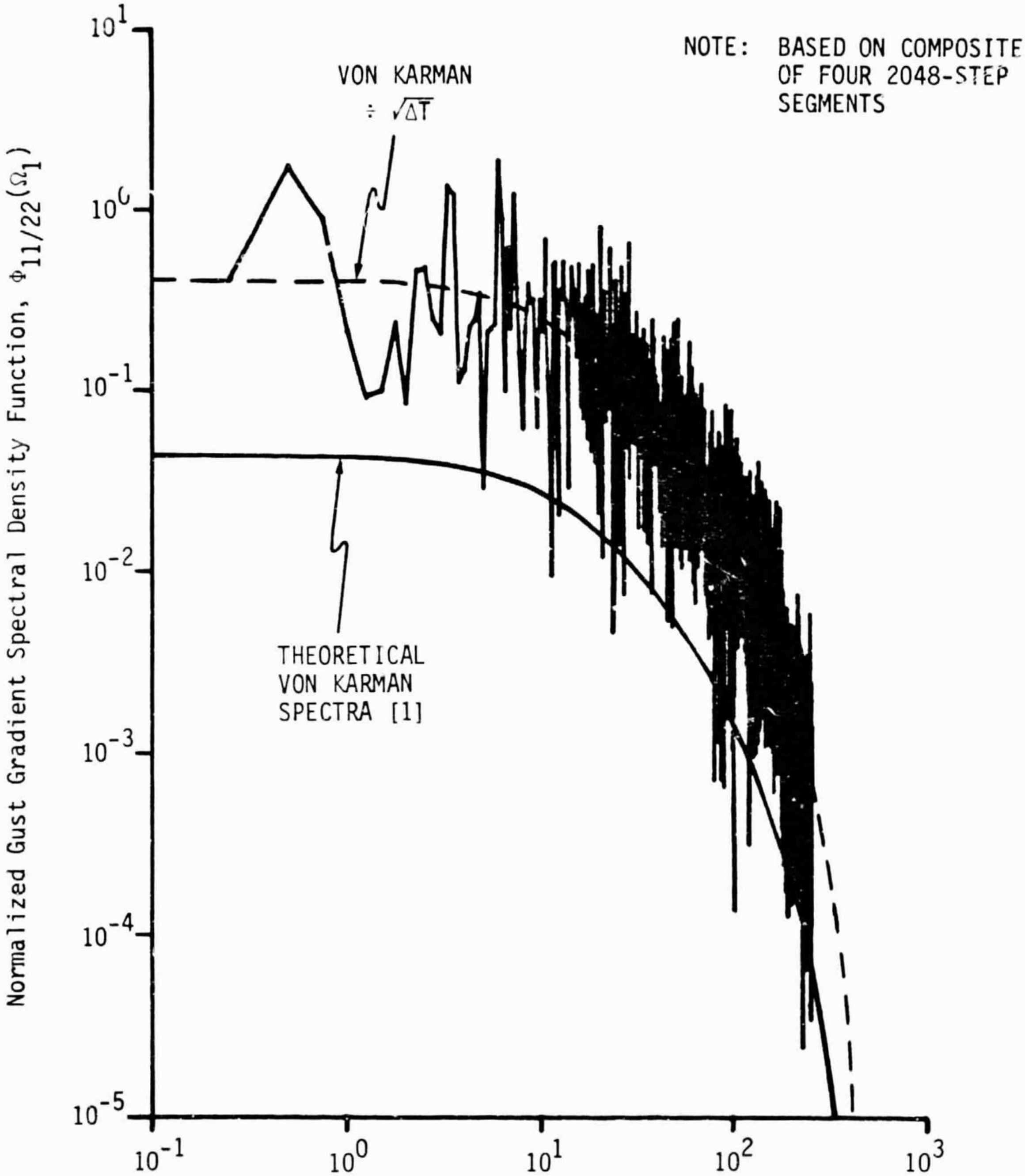

Figure 2-5. Computed $\Phi_{11/22}$ Spectra Based on Analysis of Tape 5.

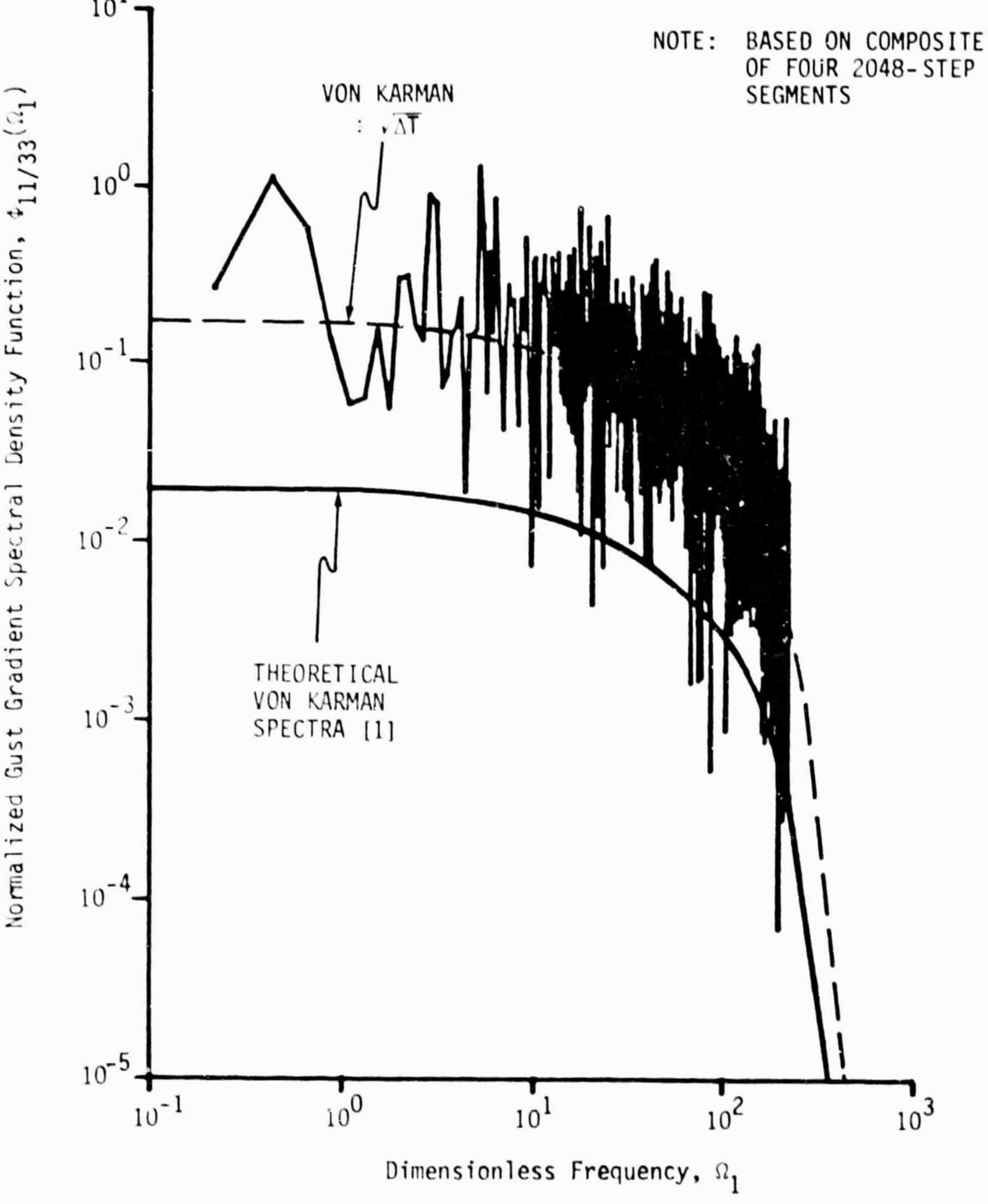

Figure 2-6. Computed $\Phi_{11/33}$ Spectra Based on Analysis of Tape 6.

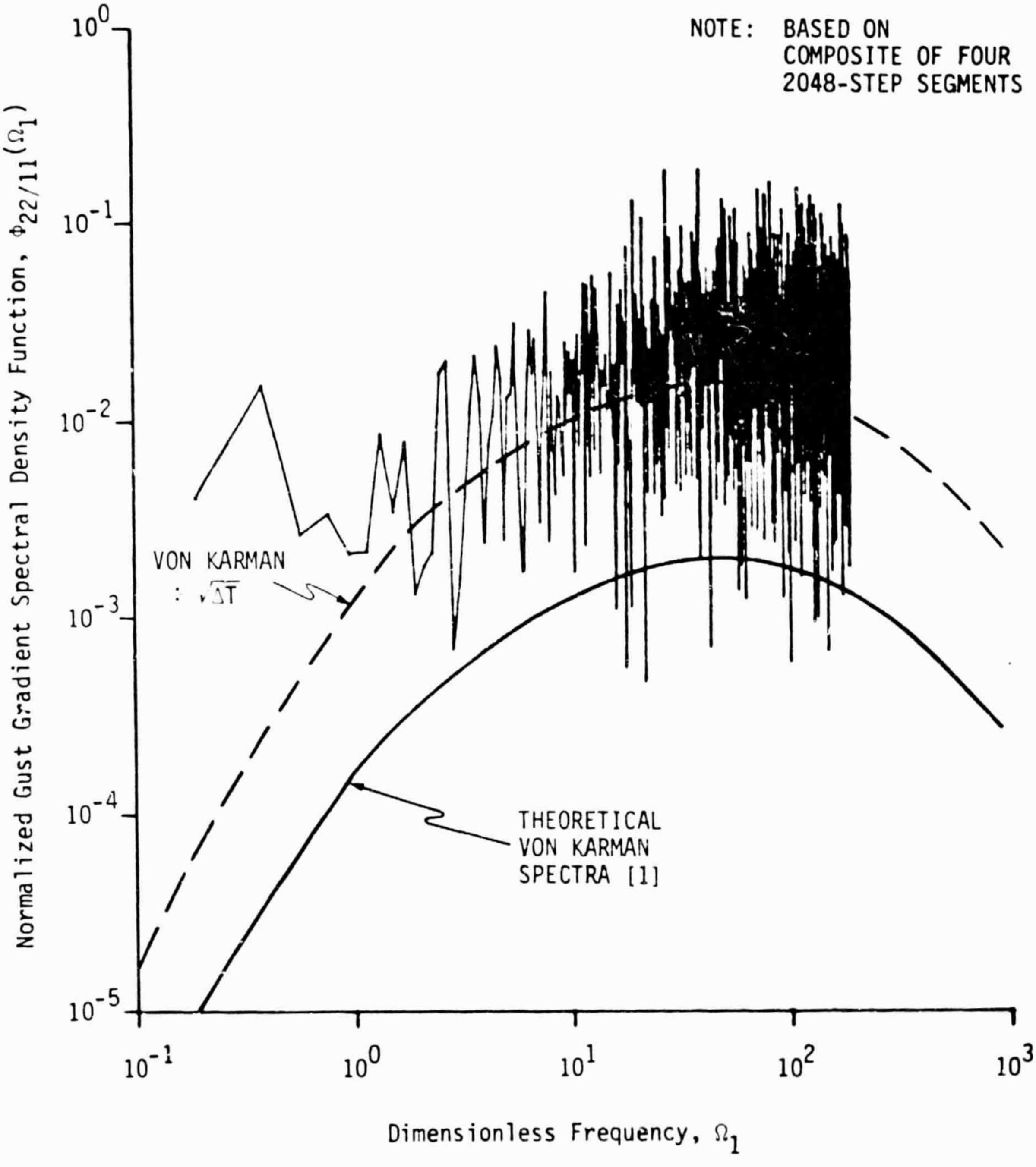

Figure 2-7. Computed $\Phi_{22/11}$ Spectra Based on Analysis of Tape 7

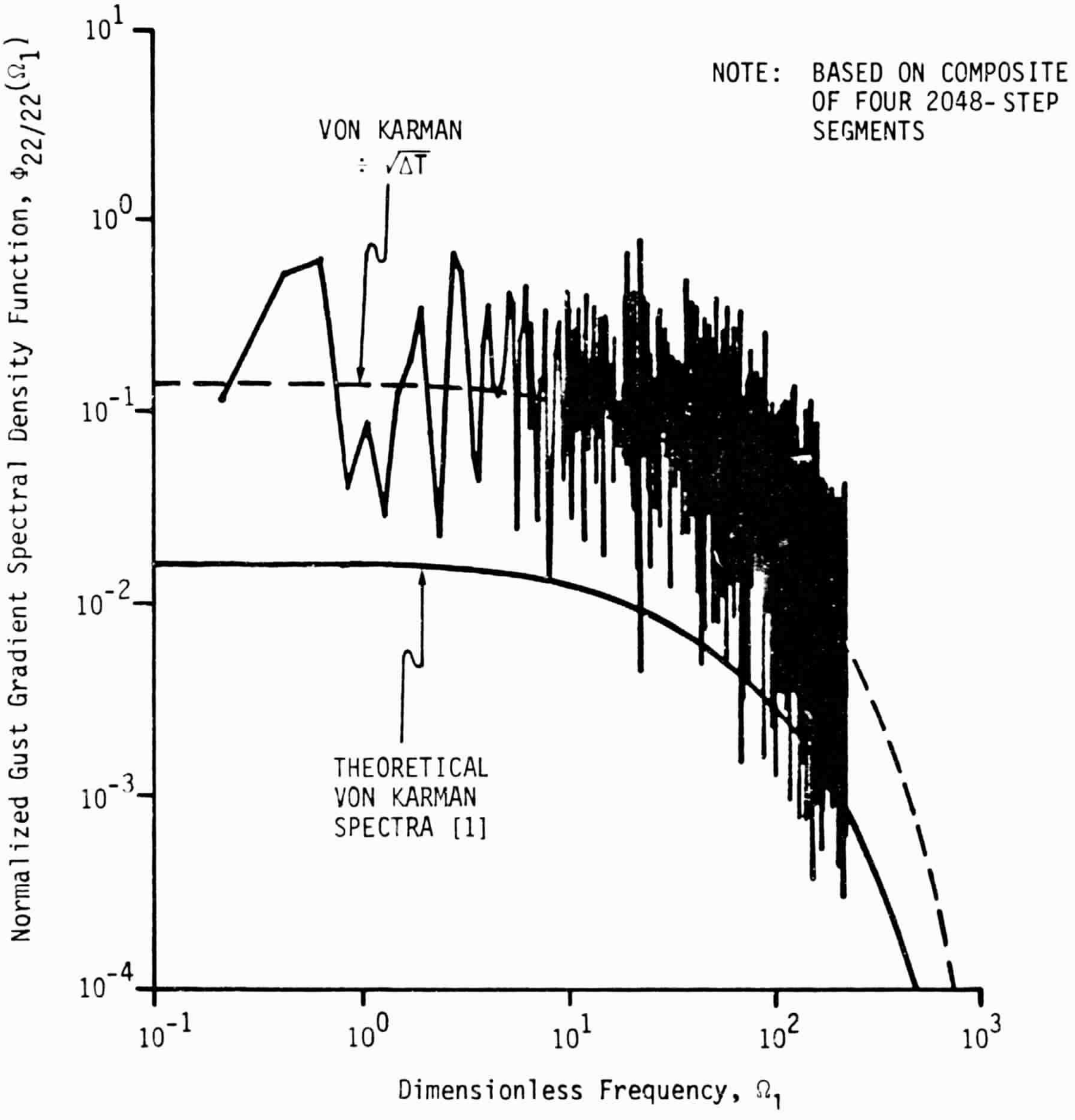

Figure 2-8. Computed $\Phi_{22/22}$ Spectra Based on Analysis of Tape 8.

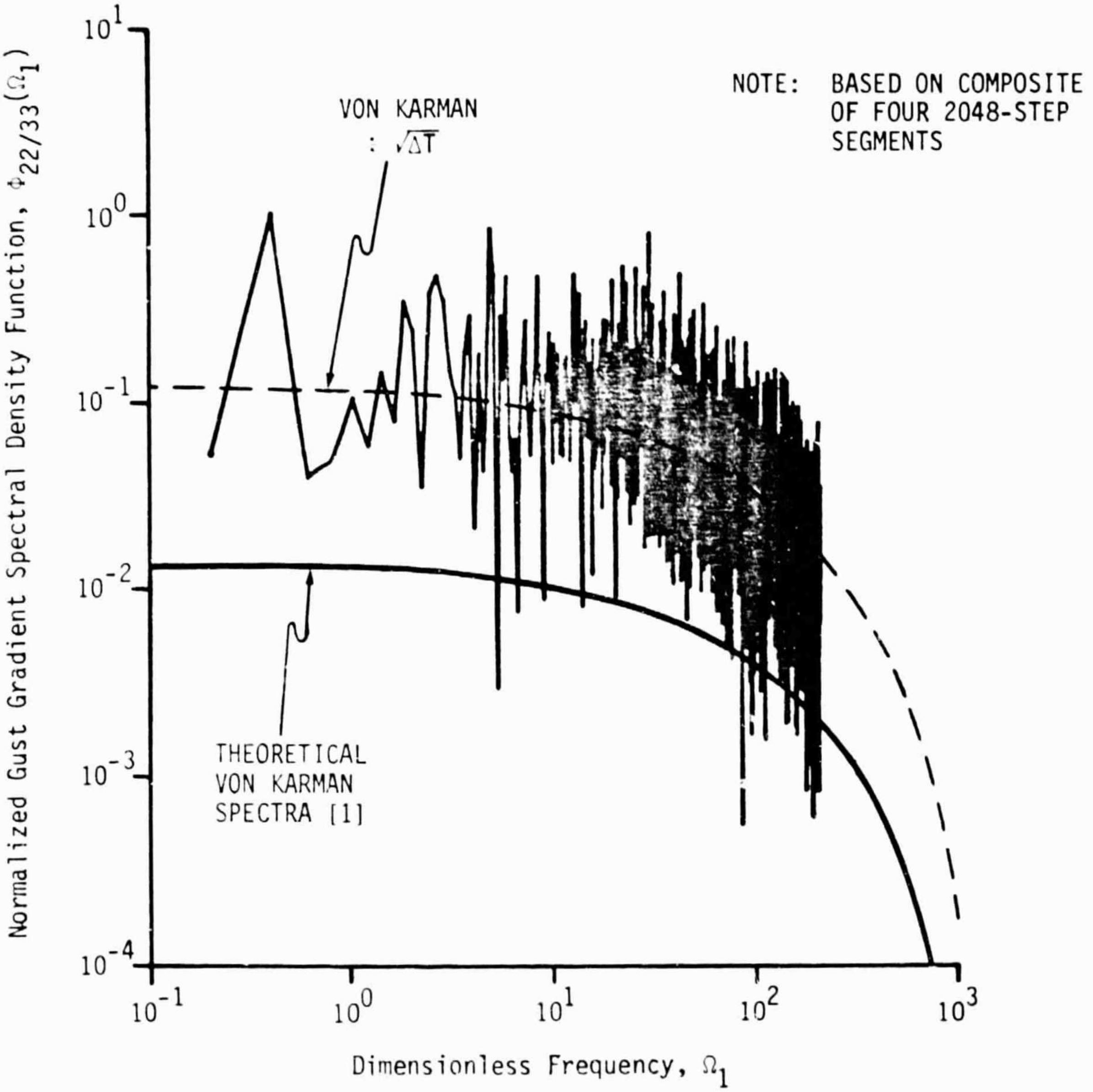

Figure 2-9. Computed $\Phi_{22/33}$ Spectra Based on Analysis of Tape 9.

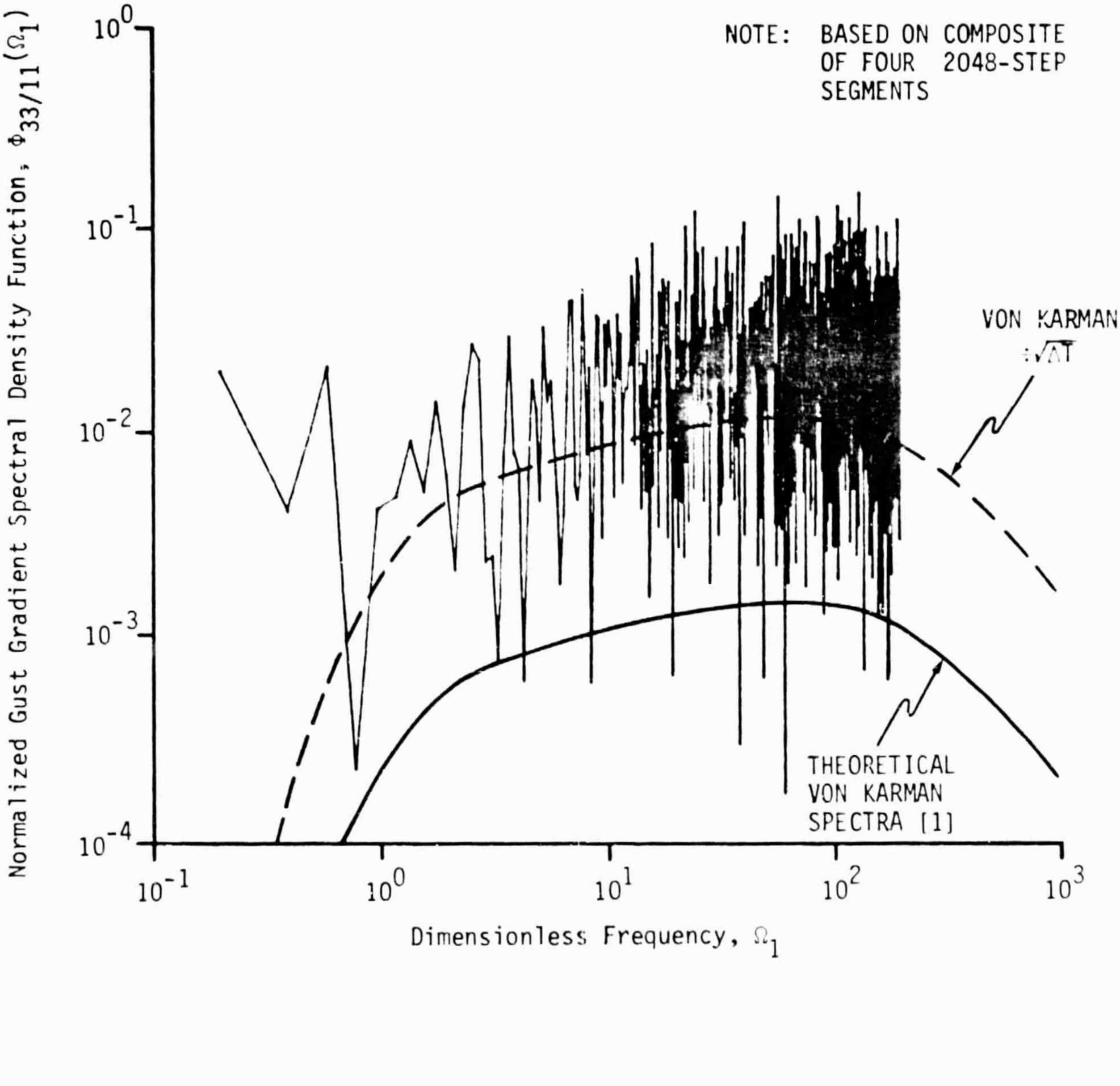

Figure 2-10. Computed $\Phi_{33/11}$ Spectra Based on Analysis of Tape 10.

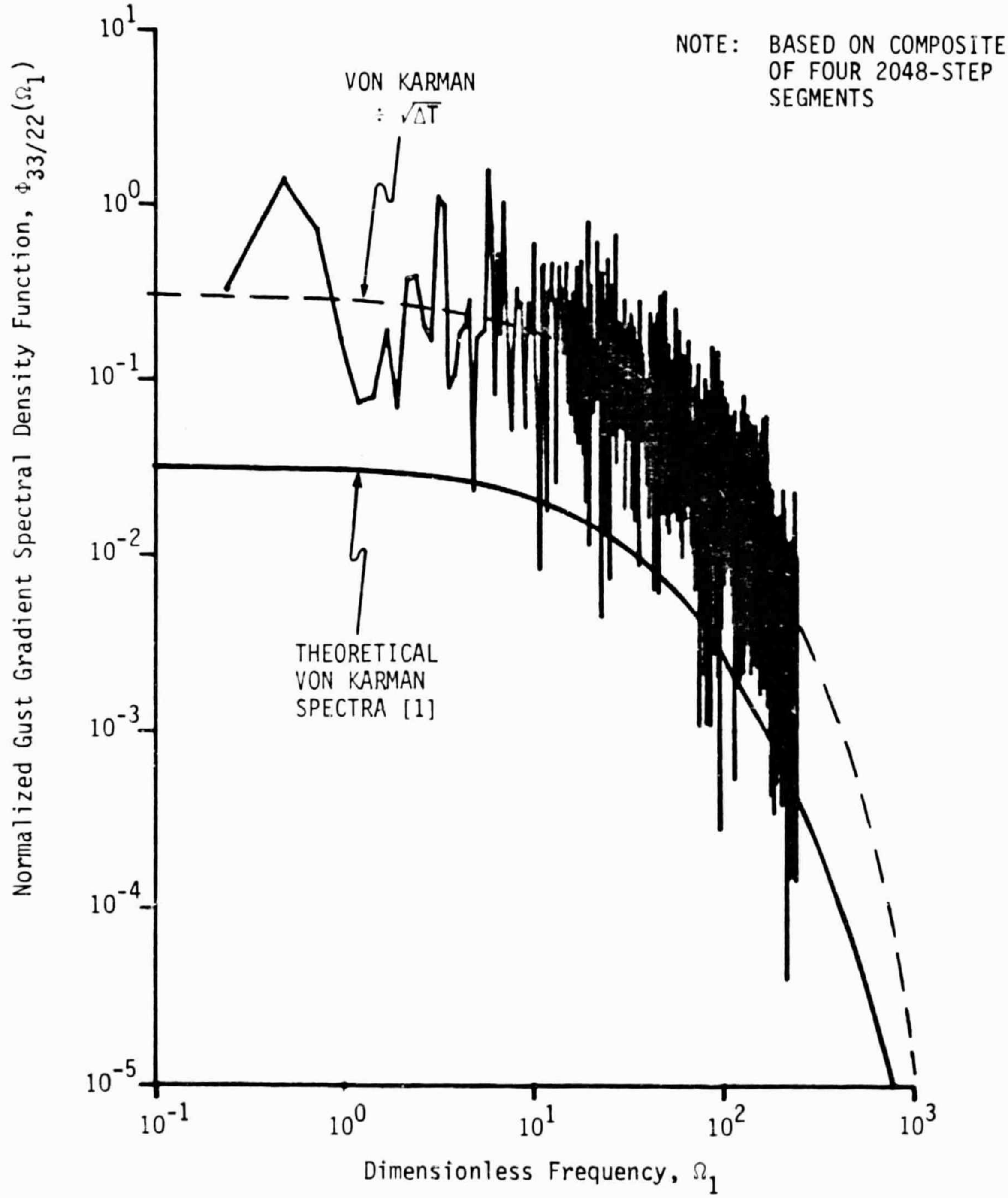

Figure 2-11. Computed $\Phi_{33/22}$ Spectra Based on Analysis of Tape 11.

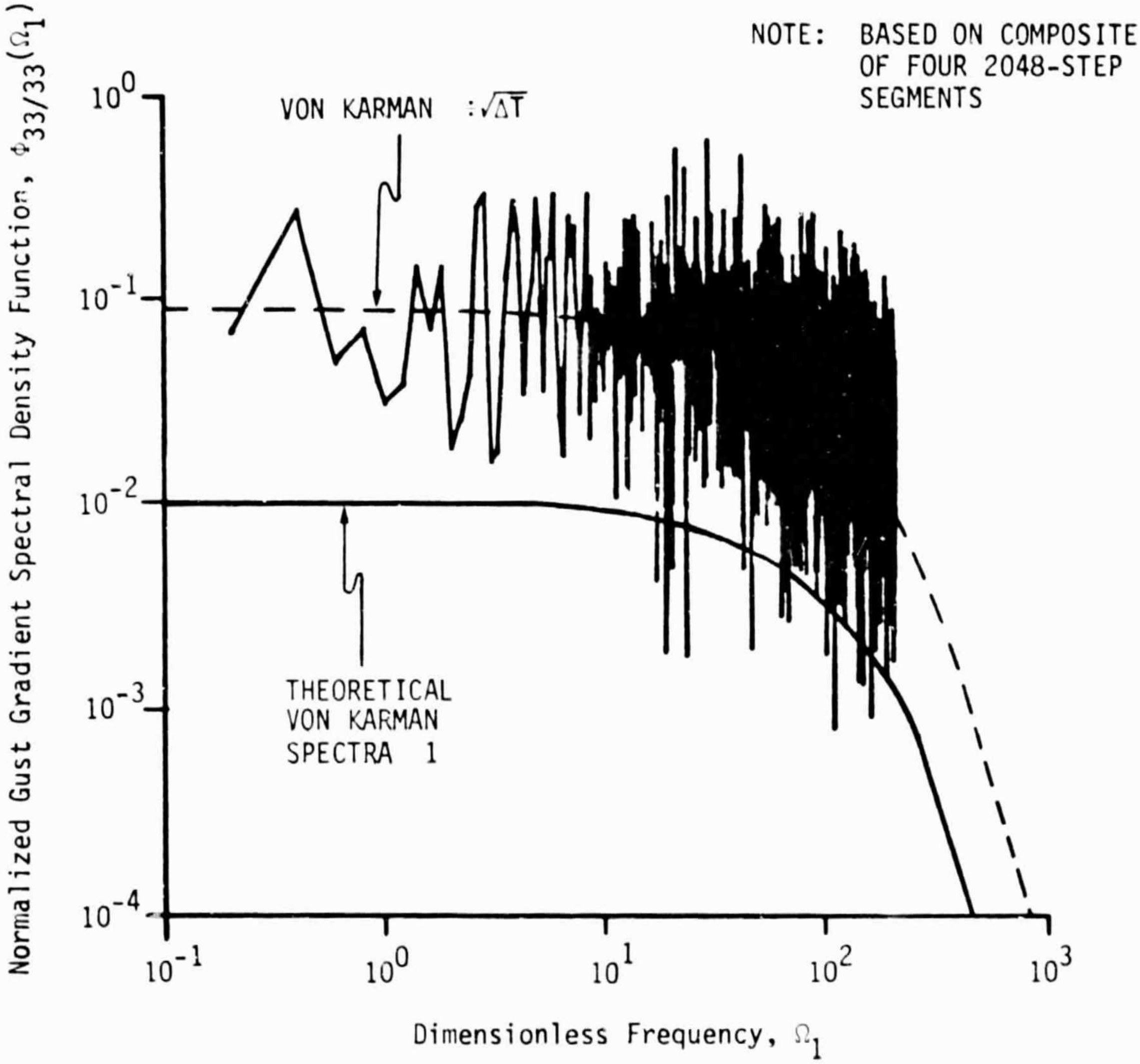

Figure 2-12. Computed $\Phi_{33/33}$ Spectra Based on Analysis of Tape 12.

where

$Y_x(n)$ = simulated turbulent signal

$h(\ell)$ = $h(\ell T)$

= $h(t)$ (the impulse response function)

$X(n)$ = discrete sampled white noise input

No correction for the effect of digitizing is necessary.

3. CONCLUSIONS AND RECOMMENDATIONS

Spectral analysis based on Fourier transform theory has been carried out on the twelve simulated atmospheric turbulence time series. One significant difference between the computed spectra and the corresponding theoretical spectra has been detected. The cause of this difference has been determined and the necessary procedure for generating corrected time series has been established.

The basic recommendation is made that corrected turbulence time series be generated according to the new procedure. Such corrected series should then be subjected to further statistical analysis to ensure that the simulated turbulence is normally distributed with the proper standard deviation.

4. REFERENCES CITED

1. Tatom, Frank B., and Smith, S. Ray, "Atmospheric Turbulence Simulation for Shuttle Orbiter", *EAI-TR-79-004*, Engineering Analysis, Inc., Huntsville, AL, August 31, 1979.

2. Fichtl, George H., Perlmutter, Morris, and Frost, Walter, "Monte Carlo Turbulence Simulation", *Handbook of Turbulence*, Volume I, Plenum Publishing Corporation, 1977.

3. Perlmutter, Morris, "Simulation of Random Wind Fluctuations", *NASA CR-120561*, Northrop Services, Inc., Huntsville, AL, September 1974.